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Canopy management in fruit crops for maximizing productivity

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Abstract
Canopy in a fruit tree refers to its physical composition comprising of the stem, branches, shoot and leaves also the number and size of the leaves, determining the density. Canopy management in fruiting trees has been practiced over the years for increasing the productivity and quality of the fruits. Management of canopy architecture is one of the predominant technologies by which huge and unmanageable trees are properly managed to make them more productive. Canopy management is the manipulation of tree canopies to optimize its production potential with excellent quality fruits. Canopy management deals in fruit crops deals with the development and maintenance of their structure in relation to their size and shape for maximizing productivity with quality fruits. To optimize the utilization of light for increased yield of quality fruits, canopy management deserves greater attention by exploiting the various available techniques like training, pruning (dormant, summer and root pruning), branch orientation (bending), scoring, girdling, selection of proper rootstock, use of plant growth regulators, appropriate use of fertilizer, deficit irrigation, use of genetically engineered plants with altered architechtural characters would help in maintaining the ideal canopies of trees. The basic objective of canopy management is to maximize light interception to optimize light distribution within canopy and to maintain proper airflow. Canopy management enhances productivity, improves fruit quality, facilitates cultural practices and help in management of pest and disease. In new plantations initial training and pruning is given to develop strong framework of the tree whereas in old plantation the aim of canopy management is to reduce tree height and make provision of solar radiation inside the canopy by thinning excessive biomass.

Keywords: Pruning, thinning, training and plant growth regulators

Introduction
Canopy in a fruit tree refers to its physical composition comprising of the stem, branches, shoot and leaves also the number and size of the leaves, determining the density. Canopy management is the manipulation of tree canopies to optimize the production of quality fruits. The canopy management, particularly its components like tree training and pruning, affects the quantity of sunlight intercepted by trees, as tree shape determines the presentation of leaf area to incoming radiation. Fruit plants become tall and huge if they are not managed by proper training and pruning from the initial stage. For harvesting the sun, each plant must establish its optimum canopy spread at earliest of its life cycle. Management of canopy architecture is therefore one of the predominant technologies by which huge and unmanageable trees are properly managed to make them more productive. It not only involves just pruning and tree training but also includes the regulation of flowering and fruit growth.

Features of ideal canopy
- Strong frame of primary branches
- Wider crotches in scaffold branches
- Healthy and well distributed secondary and tertiary branches
- Sufficient fruiting terminals in most productive areas
- Healthy foliage with high photosynthetic efficiency to maximize the solar radiation use efficiency
- Enough space for air circulation inside canopy
- Should support adequate shade to protect the fruits from sunburn

Objective of canopy management
The basic objective of canopy management is to maximize light interception to optimize light distribution within canopy and to maintain proper airflow. Canopy management enhances productivity, improves fruit quality, facilitates cultural practices and help in management of pest and disease. In new plantations initial training and pruning is given to develop strong framework of the tree whereas in old plantation the aim of canopy management is to reduce tree height and make provision of solar radiation inside the canopy by thinning excessive biomass. The objectives of canopy management are

- Maximum utilization of light
- Avoidance of built-up microclimate congenial for diseases and pest infestation
- Convenience in carrying out the cultural practices
- Maximizing productivity with quality fruit production
- Economy in obtaining the required canopy architecture
- To facilitate cultural practices
- To increase input use efficiency
- Efficient use of pesticide and fungicide

Techniques for canopy management
Orchard architecture largely depends upon the orchard production system, which is a combination of variety, rootstock, tree spacing, training and pruning. To optimize the utilization of light for increased yield of quality fruits, canopy management deserves greater attention by exploiting the various available techniques like training, pruning (dormant, summer and root pruning), branch orientation (bending), scoring, girdling, selection of proper rootstock, use of plant growth regulators, appropriate use of fertilizer, deficit irrigation, use of genetically engineered plants with altered architectural characters would help in maintaining the ideal canopies of trees.

Pruning
Pruning has been defined as the art and science of cutting away a portion of the plant for horticultural purposes. Pruning can be used to improve tree shape, to influence its growth, flowering and fruitfulness, to improve fruit quality, to repair injury, to contain the plant and to encourage light and spray penetration. Norton (2002) [28] reported that intensive pruning stimulated the regeneration processes as well as modifies the size of tree crowns, particularly decreasing the excessive tree height. Pruning establishes the structure of the tree, its shape and form, provides a framework to support the crop and facilitates mechanical operations. As tree ages, pruning removes broken and diseased wood, stimulates new growth, and provides essential light distribution throughtout the tree for the formation of strong fruit buds and essential acceptable fruit quality with appropriate fruit color, soluble solids, and ripeness.

Types of pruning and their influence on tree growth and cropping
Several experiments conducted during the early part of the twentieth century indicated that pruning delayed fruiting, reduced yields and tree size, but locally invigourate shoot growth. This led to the common opinion that pruning was a dwarfing process. Recent studies show the response of the tree to pruning depends upon the time and degree of pruning, the variety, tree age, orchard site and specific training system used. The various types of pruning include:

Summer pruning: The selective removal of shoots or branches during the growing season.

Dormant pruning: The same as summer pruning, except that cuts are made during the dormant season before active new growth has begun.

Summer tipping or pinching: The removal of the apical bud of shoots or spurs during the growing season.

Hedging: The indiscriminate removal of all branches within a plane, in either the summer or the dormant period

Heading cut: A cut made anywhere below the terminal bud on a shoot, but not the total removal of the shoot.

Thinning cut: Total removal of the shoot or branch at its insertion point on a large branch or scaffold.

Effect of pruning on yield
Results of numerous experiments indicate that pruning influences yield and regularity of bearing. The result greatly depend on tree age and growing conditions, both of which exert a simultaneous influence on tree at the time of pruning. Depending on studies, yield can be higher (Avilan *et al,* 2003; Reddy and Kurain, 2011) [6, 32], similar (Albarracin *et al*., 2017) [2] or lower (Oosthuyse, 1997) [30]. Grubb (2002) concluded that young trees on very dwarfing rootstock will fruit even when severely pruned, while similar trees on vigourous rootstock delay cropping as a result of pruning. Kumar *et al* (2010) [20] while studying effect of pruning on peach yield concluded that fruit yield decreases with the increase in severity of pruning. He also said that the average size and weight of fruits, i.e. length and width was significantly increased with the increased severity of pruning. The response of cultivar to different pruning level may be due to the size of leaves ad number of leaves per shoot which in turn effect the amount of the photosynthates.

Training
Basic objectives of training is to control vegetative vigour, increase light exposure for fruit/ foliage, increase air flow to prevent disease infestation and facilitate pruning and harvest methods and mechanization. While deploying the training systems, utilization of vertical and horizontal space should be taken into consideration. The choice of training system is a part of whole orchard management influencing planting distances, light interception and finally the success of the orchard in terms of obtained fruit quality and quantity. Training utilizes various techniques, including pruning, to direct tree growth or form and the development of the structural framework of the tree. The various training methods that are used to control tree growth in many orchards are

A: Bending: Physically bending a branch of an apple tree results in a reduction in terminal shoot growth and a redistribution of growth hormones, particularly auxin. The stress created by bending has been shown to result in increased ethylene content in the internal air spaces within the branch (Robitaille and Leopold, 1974). Forshey *et al.* (1992) [33, 14] suggested that the reduced vegetative vigour in limbs that are bent reduces the production of gibberellins, which are antagonistic to flowering. The formation of moderately vigorous lateral shoots and spurs creates additional sites for flower formation. These two effects result in increased flowering and earlier fruiting. Fruit quality is also improved because of improved light penetration and because more fruit hang free instead of rubbing against the branch on more upright limbs. The influences of auxin begins just below the shoot tip and, as the orientation away from vertical increases, the auxin influence progresses down the branch and buds on the upper side are released from the hormonally induced apical dominance and begin to grow. Thus, the more the branch orientation is changed towards the horizontal, the greater the number of shoots released towards the branch base. A field study over 5 years with 'Golden Delicious'/M.9 found that inclining the trunk atplanting 45° or 60° from the vertical reduced the rate of shoot elongation by 40% and trunk circumference growth by 17% and 27%, respectively (Bargioni *et al.*, 1995). Samant *et al.*, (2016) [7, 35] while working on crop regulation in guava concluded that branch bending improved fruit physical parameters, *viz*., TSS and vitamin C content; and also has positive influence on shoot growth, flowering intensity and yield. He also recorded maximum value for winter crop (26.48 kg /plant), this was significantly more than the cumulative yield of both rainy and winter crop obtained under control (22.5 kg /tree). Sarkar *et al.*, (2005) [36] also reported improvement in off season fruit yield over control due to branch bending. Also (Abd EL-Rahman, 2002) [1] noticed that, winter bending (1 and 5 Novembers in both seasons) with two angle 45º for three year-old shoots while 90º angle for one and two year-old shoots enhancing vegetative growth, quality and fruits quantity of "Le Conte" pear trees. Moreover, bending significantly increased C/N ratio of spur wood on 2 and 3-year old shoots but significantly decreased this ratio on one year old shoots, bending increased IAA, GA3 and decreased ABA level, furthermore (Jana, 2015) [19] noticed that, growth retardant chemicals like SADH and shoot bending increase ethylene synthesis in damaged cells which influence early flower bud formation in pear plant also (Zhang, *et al*. 2015) [41] observed that ABA and ZR concentration in shoot terminals increased but IAA and GA3 concentration decreased as the bending angle increased from 70 to 110 degrees of apple trees. Mohamed, 2012 reported that, shoot bending of two and three years old shoot at mid November or shoot girdling on three years old (5mm in width) at mid April increased number of spurs, fruit set percent, total number of fruits per tree, total yield (ton / fed) and improved fruit quality of 5-years-old"Le Conte" pear trees.

B: Scoring, Girdling Or Ringing: Scoring and ringing, which cause the interruption of the downward flow of carbohydrates and hormones in the phloem, have been shown to alter growth and fruiting. Scoring, which is a circumscribing cut through the bark, but not into the wood, has the smallest effect. Ringing, which removes different amounts of bark in a circumscribing ring, increases in severity with the amount of bark that is removed until the ultimate of tree death occurs when the tree is unable to form new tissue to bridge the ring. Scoring and/or ringing interrupt phloem translocation, which causes a build-up of the products of photosynthesis in the portion of the tree above the cut. A number of studies show that phloem interruption reduced terminal growth, trunk cross-sectional area, shoot diameter and number of shoots (Autio and Greene, 1992). Elfving *et al.* (1991) [5, 11] found that trunk scoring or ringing increased soluble solids and retarded loss of flesh firmness before harvest and following storage, but had little effect on starch hydrolysis. 'McIntosh' fruit were longer and had larger pedicel diameters and weights and more colour from trees that were ringed. Girdling apple limbs or trees inhibited vegetative growth (Greene and Lord 1983) [16] promoted the formation of flower buds, thereby increasing bloom density, fruit set, fruit size and yield (Wei, 1993 and Li-Tain *et al*., 1996) [40, 22]. On orange (Monselise *et al*., 1972) [25] reported that girdling increased endogenous gibberellins' contents and their activity. They may act in a double way, causing both abortion of late flowers which are in the first stages of differentiation and increasing setting of ovaries of earlier flower. There is another effect of girdling on fruit characters. It stimulated spurs formation at basal part of shoot in Le-Conte cv., also increase ABA, IAA, total carbohydrates % and C/N ratio in buds of all tested cultivars. From another way, girdling decrease in total nitrogen and this may be caused a chemical state that enhanced formation of flowering spurs (Fayek *et al*., 2004) [12]. On the other hand, the amount of diffusible indolle-3-acetic acid (IAA) in shoots of Japanese pear was decreased when the vertical shoots were bent at an angle of 45º which inhibited IAA transportation. It caused increasing of flower bud formation in Kosui cv. (Ito *et al*., 2001). Choi Seakwon and Kim KyuRqe (2000) [18, 10] revealed that, girdling and girdling + pinching treatments on Sekaiichi apples markedly reduced June drop and accelerated fruit growth in early stages of fruit development. Girdling + pinching and pinching only reduced bourse shoot growth compared with non treated controls. There were no significant differences in flower bud formation in the following year among treatments-it was assumed that the optimum period for girdling is the 5 days leading up to full bloom.

C: Notching: Notching is a phloem-interruption technique used to stimulate lateral branching from buds that would not normally grow. The technique removes a 2–3 mm wide strip of bark directly above a bud. The cut extends down to the secondary xylem and around about one-third of the circumference of the stem. Notching stimulates lateral branching by interrupting the downward movement of auxin from the shoot tip (Tamas, 1987). McArtney (2015) [23] reported that that notching of para-dormant bud on young 'Granny Smith' / 'M.26 EMLA' trees at pink bud stage resulted in new growth developing on 59% of notched buds. Similarly notching paradormant buds on the leader of 'Fuji/ M.9 T337' trees increased budbreak with 83% of new growth developing into extension shoots.

D: Training Systems: each fruit and nut species has a preferred training method based on the species growth habit and fruiting characteristics. Ideally, most of the fruit should be produced low in the tree to facilitate fruit thinning, pest management, and harvest. Because fruit is produced on spurs (for most of the fruits) or 1-yeart old branches (for peaches and nectarine) that require sunlight for flower development, direct sun must penetrate into the lower portions of the canopy for fruit production in fruit trees. Basic training systems include: the central leader system, the modified central leader sytem and open centre system.

A central leader tree is characterized by one main, upright trunk, reffered to as the leader. Typically trees have 3 to 4 tires of branches spaced along the trunk at height of 4-5 m. the bottom tire of branches is 60 to 90 cm above the ground and has 4 to 5 branches. The second tier of branches is commonly 60 cm to 1 m above the first tier and has 4 branches. The third and fourth tires are spaced about 60-80 cm apart and typically have 3 branches. Spreaders placed between the trunk and branches, to spread the branch angle to a desirable range of about 60 degrees. The shape of a properly trained central leader tree is like that of a Pyramid. The lowest scaffold whorl branches will be the longest and the higher scaffold whorl of branches will be progressively shorter to allow maximum light penetration into the entire tree. There are various systems that use a central leader concept *viz* spindle bush, vertical axis, slender spindle, super spindle etc. The major differences between central leader derived systems include tree density, height, leader management and whether or not permanent scaffold branches are retained.

Modified central leader system, also called the multi- leader system, is much like the central leader, but multiple vertical branches are trained instead of a single, main leader. The system works best with 3 to 5 leaders so the tree is well balanced. Rather than remove competing vertical branches in the first two years after planting, the desired number of leaders are left on the tree and each is trained in the same way as with a central leader system. Spreaders are almost always required in order to open up space between individual leaders.

In open centre system (also known as the open head or vase form), the trunk is allowed to grow upto 75 cm cutting within a year of planting. The central leader is removed, leaving three to five evenly spaced scaffold branches growing from the trunk in a vase shape. The correctly pruned tree has three well distributed limbs that will become scaffolds. A stub left in the middle will form a bushy centre which will ecourage the main scaffolds to grow outward. Thereafter prune the three scaffolds to an outside-growing, strong limb. This system lack strong crotches and provide weak framework and as such is less satisfactory. However, it may be favoured in fruits like peaches, nectarines and plums for admitting more sunlight for better colouration of the inside fruits.

Hampson (2004) [17] while studying the effect of three training systems on apple fruit trees concluded that as the tree density increased, per tree yield decreased, but yield per unit area increased. He also concluded that main advantage of high density planting was a large increase in early fruit yield. Training system had no influence on productivity for first 5-years, but during the second half of the trial, fruit yield per tree was greater for the Y trellis than for either spindle form at lower densities but not at higher densities. Also the slender and tall spindles were similar in nearly all aspects of performance, including yield.

Arsov *et al* (2013) [4] while working on jonagold apple also showed statistically significant effect of different training systems on yield and fruit quality. The trees that were grown under slender spindle system showed highest yield whereas those on V-system showed had lowest. Also highest value for fruit weight was also obtained at slender spindle and solex whereas the ones from the V- system has lowest value for fruit weight.

Plant growth retardants

The group of the bioregulators that modify aplant in its growth and developmental behaviour without including phytotoxic or malformative effects includes synthetic substances known as growth retardants. When used in appropriate concentration, these compounds influence the plant architecture in a typical fashion, such as

a. Inhibition of shoot growth (plant height, internode elongation, leaf area) with unchanged number of internodes and leaves and with intensified green leaf pigmentation and
b. Maintained or slightly promoted root growth (main roots often longer and thicker).

In both cases the root – shoot ratio is changed in favour of the root.

There are at least 3 basic methods as how plant height is controlled by chemicals:

- By killing the terminal buds or branches or severely inhibiting apical meristematic activity.
- By inhibiting internode elongation elongation without disrupting apical meristematic function.
- Reduced apical control.

Terminal bud destruction: Some of the most effective inhibitors, maleichydrazide (MH), triidobenzoic acid (TIBA) fatty acids, ethylene and ethylene releasing compounds such as ethephon and ethyl hydrogen propyl phosphate act by killing the terminal bud or by causing severe disruption in apical meristematic functions (Sach and Hackett, 1972) [34]. In some species ethylene, TIBA, Napthylpthalamic acid (NPA) and others have been shown to inhibit polar auxin transport. Hence the inhibition of stem elongation observed may reflect reduced auxin level in tissues below the apical meristem, too. These compounds usually alter geotropic responses, cause auxiliary bud break, or induce early leaf abscission as well as reduced stem elongation.

Internode elongation inhibition: The effect of retardants on stem growth occurs on the subapical region of the shoot tip where cell division and, to a lesser extent, cell elongation is inhibited. Thus, internodes of retardant-treated plants are shorter primarily because they possess fewer cells. Many growth retardants like succinic acid, 2, 2-dimethylhydrazide (SADH) and 2-chloroethyl trimethyl ammoniumchloride (CCC or chlormequat) act by inhibiting a specific step in the synthesis of naturally-occuring gibberellins, which is necessary for the maintenance of subapical meristem activity. When such retardants are used, it is possible to reverse the inhibitory effect in intact plants by the application of an appropriate dose of GA3 (Nickell, 1994) [27].

Reduced Apical Control: Reduction in plants height can also be achieved by stimulating the growth of auxiliary buds and branches which will compete for minerals, nutrients, hormones and other metabolites thus reducing the growth of main stem. In general, branched plants are shorter than those with a single axis. Application of 6-benzylamino purine and Gibberellin A4 +7 (Forshey, 1982) [13] and Promalin (6-benzlamino purine plus gibberellins A4 +A7) (Miller, 1983) [24] increased spur and lateral shoot development. The cytokinins apparently promote growth directly in the auxiliary buds rather than by inhibiting terminal meristematic activity or by inhibiting auxin transport.

Use of growth regulators in fruit crops

Significant reduction in shoot length was observed with three sprays of Maleic Hydrazide (MH 500 ppm at leaf stage followed by 1000 ppm at leaf stage and 1500ppm at 15 leaf stage) when compared to control. Shoot length was not significantly reduced by any of the 2-chloroethyl trimethyl ammonium chloride (CCC) treatments. None of the treatments reduced the intermodal length measured between 5th and 6th; 10th and 11th; and15th and 16th nodes significantly when compared to control. However application of CCC at 5 leaf stage was more effective than other treatments in reducing the internodal length between 5th and 6th; 10th and 11th; and between 15th and 16th nodes. Maleic hydrazide (MH) seemed to be more effective than CCC in increasing the cane diameter in Thompson Seedless grape (Shikhamanyand Reddy, 1989). Lichev *et al.* (2001) [37, 21] found that application of cultar (25% paclobutrazol) significantly inhibited the annual shoot growth and improves photosynthetic activity which may increase yield in cherry. Application of paclobutrazol 10 g / tree in mango resulted reduced tree height (21.20%), tree volume (33.1%) and mean shoot length (48.2%). This response was attributed to GA – inhibitory activity of paclobutrazol (Murti *et al.*, 2001) [26]. Albuquerque *et al.* (2000) found that application of 1500 ppm CCC increased the number of fruiting buds in grape. In red raspberries cv. 'Autumn Bliss' Ghora *et al.* (2000) [15] conducted an experiment on effect of growth retardants (CCC, daminozide and paclobutrazol) on growth and development under plastic green house condition and found that application of 500 ppm CCC enhanced anthesis and fruit ripening by about 10 days. In an experiment on effect of growth substances on flowering and fruiting characters of 'Sardar' guava. Brahmachari *et al.* (1995) [9] reported that application of ethrel at 25 or 50 ppm in guava enhanced fruit set percentage, weight, quality of fruit while, reduced number and weight of seeds thereby increased pulp / seed ratio. In a study on induction flowering in off year mango cv. "Alphonso" asinfluenced by chemicals and growth regulators, the foliar spray of ethrel @ 200 ppm has increased number of flowers /panical. (Vijaylakshmi and Srinivasan, 1998) [39]. Turn bull *et al.* (1999) [38] studied routes of ethephon uptake in pineapple and reasons for failure of flower induction and found that ethylene releasing agents such as ethephon are used widely to induce flowering in pineapple. Likewise, Similarly, Ramburn (2001) [31] reported that foliar application of 0.5 gm PBZ + 0.4 gm ethephon / l promoted flowering in litchi with erratic fruiting. Onaha *et al.* (2001) [29] found higher percentage of flower bud induction in pineapple by application of ethephon. The use of growth retardants have an important impact on the economic production of fruit crops by incorporating more trees in a given area of land because of their reduced tree height, canopy size and spread. This has resulted in increase in the fruit yield at the expense of only cost of chemical and its cost of application. Thus, the increase in final production is at no extra purchasing of land, no extra tilling of land, no addition of extra fertilizers, no extra weed control or other pest control measures. However, judicious use of growth retardants which have been properly registered and experimented with no harmful effects on humans and environment are only to be allowed for commercial use in agriculture.

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